

Final Report
NASA/USRA Universities
Advanced Engineering Design Program
at the
University of Illinois
for the
1987-1988 Academic Year
by
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and
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Abstract

This report reviews the participation of the University of Illinois at Urbana-Champaign in the NASA/USRA Universities Advanced Engineering Design Program (Space) for the 1987-1988 academic year. The University's design project was the Manned Marsplane and Delivery System. In the spring 1988 semester, 107 students were enrolled in the Aeronautical and Astronautical Engineering Departments' undergraduate Aerospace Vehicle Design course. These students were divided into an aircraft section (56 students), responsible for the Marsplane design, and a spacecraft section (51 students), responsible for the Delivery System design. The design results were presented in Final Design Reports, copies of which are attached. In addition, five students presented a summary of the design results at the Program's Summer Conference.

Teamed with the NASA Marshall Space Flight Center (MSFC), the University received support in the form of remote telecon lectures, telephone consultations with MSFC personnel, reference material, and previously acquired applications software. In addition, one student, who will be a graduate teaching assistant in the spring 1989 semester, was awarded an internship at MSFC for the summer of 1988.

A new course, called the Spacecraft Design Laboratory, was also started with USRA support. Ten undergraduate and graduate students participated in the design, development, and building of a prototype Terminal Operations Tether System (TOTS) for the space station.

Introduction

This is the third year that the University of Illinois has participated in the NASA/USRA Universities Advanced Engineering Design Program. The participation is through the Aeronautical and Astronautical Engineering (AAE) Department's undergraduate Aerospace Vehicle Design course (AAE 241), which is offered only in the spring semester. In keeping with the philosophy of studying a new project each year (last year's project was the Multi-body Comet Explorer), the Manned Marsplane and Delivery System was selected for this year's project.

The Manned Marsplane concept grew out of earlier studies of unmanned winged craft designed for the reconnaissance of Mars. Many of these studies were conducted in the late 1970's and remained on the shelf as interest in the Mars program waned. Recent advances in technology, and a resurgence in interest in the exploration of the Red Planet, called for a reassessment of the Marsplane concept. This view was reinforced by presentations at last summer's Case for Mars III Conference at Boulder, Colorado, which the class organizers attended. Rather than repeat the earlier studies, the University of Illinois sought to extend the technology to the design of a manned vehicle.

The project concept was approved by Frank Swalley, the University's contact at MSFC, early in the Fall 1987 semester. Details of the interaction between MSFC personnel and the University were worked out generally in the Fall of 1987 and specifically during the Spring 1988 semester. A calendar of major AAE 241 events is presented in Appendix A.

In addition, a new course, called the Spacecraft Design Laboratory (AAE 391), was made possible by the University's participation in the USRA program. Ten students undertook the design, construction and testing of a Terminal Operations Tether System (TOTS) for the Space Station.

Design Course Organization

The University's AAE 241 design course is comprised of two sections, one each for aircraft and spacecraft design. Based on individual interests and introductory information provided at the first class meeting, AAE 241 students choose one of the sections. Of the 107 students enrolled in AAE 241 in the spring 1988 semester, 56 selected the aircraft section and 51 selected the spacecraft section. The section rosters are given in Appendix B.

Usually the design sections function independently. However this year, interaction between the two sections was required for a successful design project. The aircraft section provided payload mass and size requirements to the spacecraft group, which in turn provided injected mass and size capability. One aircraft group was paired with one spacecraft group (with one exception where one spacecraft group was paired with two aircraft groups).

The AAE 241 staff was as follows.

Course Director	Kenneth R. Sivier
<u>Aircraft Section</u>	
Section Leader	Kenneth R. Sivier
Graduate Teaching Assistants	Douglas Anderson John Henderson
<u>Spacecraft Section</u>	
Section Leader	Michael F. Lembeck
Graduate Teaching Assistant	John Reilly
Undergraduate Teaching Assistant	Teresa Armel

At the first meeting of the class, students were asked to fill out a questionnaire to identify courses they had taken and their preference of technical areas (at the Marsplane and spacecraft subsystem level). Based on these results, the students were divided into eight competing Marsplane groups and seven competing spacecraft groups. Each group was responsible for a complete design as required by the given section.

Aircraft Section: Marsplane Design

Section Organization

The 56 students choosing the aircraft section were divided into eight, seven-member, project groups. Each of the seven group members were assigned

principal responsibility for one of the following major subsystem areas.

- Aerodynamics
- Performance
- Power and Propulsion
- Stability and Control
- Structures and Materials
- Surface Operations (including take-off and landing)
- Weights and Balance

One student in each group was designated as group coordinator. That student was responsible for calling and chairing group meetings, preparing summary progress reports, monitoring group coordination and progress, and acting as the contact between the section staff and the project group. Group, technical area, and project coordinator assignments were made with reference to the preference questionnaire responses turned in at the second class meeting.

The responsibilities for the following design areas were allocated by decisions of the students within each design group:

- Auxiliary Systems
- Costs
- Internal Configuration
- Packaging and Assembly
- Rescue Scenario
- Spacecraft Interface

Marsplane Specifications

The Marsplane specifications, as given to the students, are presented in Appendix C.

Course Schedule

The schedule of the aircraft section activities is presented in Appendix D. With respect to the schedule, the design activities in the aircraft section were divided roughly into four phases:

1. Initial Sizing The method presented by Lofton (Reference 1) was used during the first two weeks of the semester to carry out an initial sizing exercise. The students worked independently, with each student submitting results of the exercise. These results were then used to select the initial design point for each project group.
2. First design phase Starting with the initial design point, each design group developed its phase-one design which was presented in the midterm written and oral reports.
3. Second design phase After the midterm reports were reviewed and critiqued by the section staff, each design group proceeded to develop its final design. This phase ended on the design freeze date.

4. Documentation phase The period, from the design freeze date to the final written report submission date, was spent carrying out final design analyses and preparing the final written design report (FDR).

The design results were presented in the written FDR's and oral presentations to the entire AAE 241 class.

Lectures

The section staff presented a series of lectures on the several technical areas during the first and second design phases. These were reinforced with homework assignments and quizzes. The students attended only those lectures dealing with their assigned areas. The lectures also provided a forum for discussing technical problems as they arose during the design. The lectures began immediately after the initial sizing exercise was completed and continued as long as necessary. For the spring 1988 semester, the responsibilities for the major technical area lectures were divided as follows.

D. Anderson	Aerodynamics Performance
J. Henderson	Structures and Materials Weights and Balance
K. Sivier	Power and Propulsion Stability and Control Surface Operations

In addition to the in-class lectures, the airplane design section students attended the following lectures.

Paul Cysz	McDonnell Douglas Corporation; National Aerospace Plane
Mel DeSart	University of Illinois Library System; Use of Library Resources
Col. Stephen Nagel	NASA; Space Transportation System Safety
Harold Huie	MSFC (telecon); Power Systems (only students responsible for power and propulsion attended)
Michael Lembeck	Spacecraft Section Leader; Cost (only students responsible for cost estimation attended)

Spacecraft Section: Delivery System Design

Section Organization

The organization of the spacecraft section generally followed that of the aircraft section. Each of the seven group members were assigned principal responsibility for one of the following major subsystems:

- Aerobrake
- Altitude & Articulation Control
- Command & Data Control
- Mission Planning & Costing
- Power and Propulsion

Science Instrumentation Structures

Each project group, in turn, selected a leader responsible for group coordination and preparation of weekly status reports to the section staff.

Delivery System Specifications

The Delivery System Request for Proposal, as given to the students, is presented in Appendix E.

Course Schedule

The schedule of spacecraft section activities is presented in Appendix F. Fifteen homework assignments were assigned in the spacecraft section, exposing all the students to subsystem design analysis. Several of these assignments required the students to make use of software written by the teaching assistants and others and made available on twenty IBM AT's in an open computer laboratory. This software included:

- MIND - Mechanically Intelligent Designer, an expert system shell for which the students generated design rules to perform conceptual spacecraft design. This program is also serving as an interim tool for strategic planning at NASA/OSSA under Joe Alexander.
- MULIMP - program made available by Science Applications Interactions Corp. (SAIC) to compute interplanetary trajectories and launch estimates.
- JULIAN - program to compute Julian dates for MULIMP. AEROB - program for optimizing aerobrake shield size vs. semi-major axis vs. final injected mass, made available by former graduate student Dr. Stephen Hoffman, now with SAIC.
- INERT - program for determining spacecraft composite inertia and mass properties.
- SCSIM - scan platform dynamics and control simulation program.

All students gave a five-minute, midterm oral viewgraph presentations representing an RFP response. Emphasis was placed on the identification of requirements and trade studies to be undertaken for the final design. At the end of the semester, a Final Design Report was submitted by each project group and summarized in another oral presentation to the entire AAE 241 class.

NASA/MSFC Remote Lectures

Frank Swalley of MSFC provided reference contacts for University interactions with MSFC. As a result of these contacts, three MSFC engineers participated in remote telecon lectures. Each lecturer provided viewgraphs in advance of his presentation and copies were distributed to the students. A

question and answer session followed each lecture, allowing the students to interact with the NASA professionals in a relaxed, albeit distant, manner. Lead MSFC participants included:

Harold Huie	power systems
Bob Giubici	Marsplane propulsion systems
Joe Santos	structures

Joe Santos was last year's spacecraft section undergraduate assistant. After graduating, Mr. Santos accepted a position with MSFC. He related some of his experiences there from a new hire's perspective.

Other Guest Lectures

In addition to the MSFC telecons, several industry representatives delivered in-class presentations on various aspects of the Marsplane and spacecraft design problem. The guest lectures, their affiliations, and the topics they discussed were:

Mel DeSart	University of Illinois Library System; Use of Library Resources
John Soldner	SAIC; Earth-Mars Trajectory Options
Dr. Stephen Hoffman	SAIC; Aerobraking Technology and Applications
Col. Stephen Nagel	NASA; STS Safety.

Spacecraft Design Laboratory

A new course, Space Design Laboratory (AAE 391), was initiated in the Spring 1988 semester. Its objective was to offer a more "hands-on" design environment by including system design, assembly and testing. Ten students, undergraduate and graduate, participated. The class roster is presented in Appendix G.

The posed problem was the docking of an OMV at the space station. Specifically, the students were required to minimize thruster contamination of the immediate area while maintaining positive control of the process from the station itself. Using a locally obtained air bearing and commercially purchased air compressor, microprocessors, and electronic components, the students constructed a physical simulation of a tether-based system for retrieving the OMV.

As part of the course, students learned how to program a 6502 microprocessor in assembly language, interface simple sensors and actuators to the microprocessor, and control (in real-time) a simulation of the proposed tether reeling system. Design methodology, software development and management, component selection, systems integration, fault protection, and human factors were all covered in the course of the semester.

Results

The resulting designs were presented in the groups' Final Design Reports. Copies of these reports are included with this report. A summary report was presented at the Summer Conference. A corresponding written

summary report was submitted to USRA for inclusion in the Conference proceedings.

In addition, a paper based on the Marsplane designs will be presented at the AIAA Aircraft Design and Operations Conference in Atlanta, September, 1988. The abstract for this paper is presented in Appendix H.

Summer Program

Andrew Koepke was selected for the MSFC summer internship program. Last year, Mr. Koepke led a design team participating in the AIAA/Allied Student Design Competition calling for designs of a space station lifeboat. He was also the defacto group leader for the AAE 391 Spacecraft Design Laboratory course this spring and has been selected as one of the teaching assistants for AAE 241 for the Spring 1989 semester.

Students interested in participating in the Summer Conference at Kennedy Space Center (KSC) submitted letters of application early in the semester for review. Of the 10 students applying, five were selected. They were Daniel Jensen, Philip Lange, Laura Vanerka, Russell Wenzel, and William Woodruff.

As a dress rehearsal for the summer conference, these five students made a presentation to a special evening meeting of the University's AIAA student branch on May 11, 1988. The presentation, repeated at KSC on June 16, 1988, summarized the class organization, design issues investigated, and results obtained by the Marsplane and spacecraft design groups.

In addition to the five undergraduates, sufficient funds were available to allow Professor Sivier and teaching assistant Michael Lembeck to attend the summer conference.

Evaluation

Resources provided by the Advanced Engineering Design Program add credibility and substance to the AAE 241 Aerospace Vehicle Design course at the University of Illinois. Contact with aerospace professionals working on real problems gives the students a point of reference, early in their careers. To obtain a measure of the attitudes of the students participating in the program, they were asked to fill out a questionnaire related to the impact of the USRA program on their opinions and future careers. This was done at the special class meeting on the evening of May 11. The results of this survey are presented in Appendix I.

Of the 107 students enrolled in AAE 241, 95 attended the meeting. Only about 60% turned in completed forms. The results show that the overall impact, from the students' point of view, was positive. The reaction to the interactions with MSFC was disappointing. The in-person, guest lectures (principally from SAIC in Chicago and McDonnell-Douglas) were better received. Questions 5 and 6 should have been presented differently. Not all students made, or needed to make, contact with MSFC and only a few aircraft section students attended the telecon lectures (which were mainly for the spacecraft students). It is clear that the opportunity to meet, on campus, with MSFC engineers, would make a major improvement in the effectiveness of the interaction with MSFC.

The value of the summer intern program, to the University and to NASA, is evidenced by the acceptance of a position at MSFC by Joe Santos, last year's undergraduate teaching assistant. Mr. Santos brings to three the number of AAE 241 graduates who have participated in the USRA program and are now working at MSFC. After graduation, the 1987 summer intern at MSFC, Mark Sargent, accepted a position at the NASA Jet Propulsion Laboratory in Pasadena, California.

Program Visibility

A paper, based on the application of the MIND artificial intelligence system to spacecraft design, was presented at the 1987 ASME Annual Meeting in Boston on December 13-18, 1987. The abstract for the paper is presented in Appendix J.

As mentioned earlier, a paper based on the Marsplane design has been accepted for presentation in the Elements of Design Education session of the AIAA Aircraft Design, Systems and Operations Meeting in Atlanta, September 7, 1988. The abstract for this paper is presented in Appendix H.

Selecting the Marsplane and its delivery system as a design project has generated much interest in the Program and in the design activities at the University. Doug Isbell¹, a graduate journalism student at the University, submitted a short article on the Marsplane project to Space World magazine. The article (included as Appendix K) was published in the April 1988 issue of Space World as part of a larger article² on the Advanced Design Program. In the course of preparing the article, Doug contacted the University's News Bureau. The result was a news release (included as Appendix L). This resulted in a number of inquiries about the program including an interview of Professor Sivier for the Voice of America by Doug Weikle on April 20th and prospects of an article in OMNI magazine in fall of 1988. In addition, a condensation of the press release appeared in the Future Scope column of the July-August 1988 issue of The Futurist magazine.

Finally, the authors have been invited to present a paper on the Marsplane project at the 8th Annual International Space Development Conference in Chicago on May 26-29, 1989.

¹ Doug is an AAE graduate and participated in the AAE 241 Lunar Oxygen Transportation System study in the spring of 1986.

² Sutphin, Susan, "Designing for the Future", Space World, April 1988, pp. 17-23,31.

Comments

Participation in the Advanced Design Program is viewed positively by not only AAE Faculty but also the Department, College and University Administrations. One important example of that is the effective cost sharing achieved by waiving the overhead charge on teaching-related grants. Another example is the commitment, almost a year in advance, of funds for a graduate teaching assistant so that this summer's intern (Andy Koepke) can bring his experience at NASA to next spring's design class (he will not be paid from the USRA grant funds).

On the other hand, two characteristics of the program have caused some difficulties. They are (1) lack of firm dates and agenda for meetings far enough in advance for planning and preparation purposes and (2) increasing reporting requirements, with insufficient notice. In fairness, the longer abstract for inclusion in the Summer Conference program and the summary report for a Conference proceedings are viewed as positive additions. It is hoped, however, that they represent the final additions to the reporting requirements.

¹ At current overhead rates, a net grant of \$22,484 (including one TA) would require a gross grant of \$52,500; an effective overhead rate of about 57%.

Appendix A

AAE 241
Aerospace Vehicle Design
Spring 1988

Major Events Calendar

(Applies to both Aircraft and Spacecraft Sections)

January 26	First meeting; organization
March 1	Paul Czysz lecture; National Aerospace Plane Design
March 15 & 17	Presentation of oral midterm reports
April 21	Col. Stephen Nagel lecture; Space Transportation Safety
May 3, 5 & 10	Presentation of oral final design reports
May 11	Special evening student AIAA branch meeting; dress rehearsal of presentation for the Advanced Design Program Summer Conference

Appendix B**AAE 241
Aerospace Vehicle Design
Spring 1988**Class RosterAircraft SectionGroup 1

Ron Dunn
Sam Huber
Dan Jensen
Martin Kim
Norm Knapp
Greg Maloney
Ken Marduson

Group 4

Mike Brody
Tim Ehmke
Kurt Heier
Dan Ramshaw
Kent Sugiyama
John Walter
Arlene Zander

Group 7

Craig Barton
Nathan Fawer
Kevin Klein
Dick Kreiger
Hwa-Sup Lee
Paul Martin
Jim Sullivan

Group 2

Glen Brown
Dion Buzzard
Grant Eaton
Art Fletcher
Bryan Matz
Richard Monke
Patricia Perkins

Group 5

Paul Beckwith
Ron Cihak
Ron Golembiewski
Scott Hildreth
Terri Pulsford
Bill Woodruff
Curt Zimmerman

Group 8

Mike Croegaert
Jim Edgar
Jim Goggin
Angie Kostopoulos
Matt Miller
Jami Munson
Steve Schirle

Group 3

Mike Enright
Karen Forest
Nick Jasper
Phil Lange
Jim LeRoy
Patrick Moroney

Group 6

John Blackwood
Greg Cimmarusti
David Cloughley
Brian Fudacz
Jim Mocarski
Sonja Schillmoeller
Don Strobert

Appendix B ContinuedSpacecraft SectionGroup 1

Bill Andrews
Paul Garbe
David Kristola
Muhanned Maayeh
Joe Nedorost
Pablo Serrato
Matthew Zell

Group 2

Ed Bodony
Andrew Chudy
Garrick Goo
Mike Gorden
Peter Hjellming
Jon Taylor
Jim Wimpe

Group 3

Eric Olsen
Jay Onken
John Mutka
Mike Scheller
Tom Styber
Pam Warmack
Curt Zimmerman

Group 4

Ed Alcock
Tomaso DiPaolo
Michael Groble
Eric Gunter
Tim Hogan
Dennis Lord
Mark Scanlan

Group 5

Jeff Bradshaw
Sanjeev Dhand
Larry Kim
Sisir Kudva
Toby Martin
Peter Rachesky
Russ Wenzel
Steve Sauerwein

Group 6

Dave Cusano
Jim Dooley
Monica Doyle
William Hienz
Todd Horton
Erik Johnson
Trenton Rader

Group 7

Rick Christian
Russell DeLaney
Jim Lassa
Greg Lehmann
Jerrold Petrizzo
Laura Vanerka
Randy Weakly
Charles White

Appendix C

AAE 241
Aerospace Vehicle Design
Spring 1988

Aircraft Design Section
Marsplane General Performance Specifications

1. Payload: 1200 N.*

Two, suited astronauts with life support systems. The system will normally operate with only a pilot. The remaining 600 N. payload capacity can be used for transporting equipment and supplies and/or for a scientific instrument package.

2. Airfield Performance:

The aircraft must be able to operate out of prepared airstrips no more than 1000 m. in length.

3. Cruise Performance:

The aircraft must have an unrefueled endurance of 8 hrs. Cruise speed and the corresponding range are to be determined/selected by the design team.

4. Rescue Scenario:

The design must consider the rescue of the crew of an aircraft that has been forced to land or has crashed during its flight mission.

5. Assumptions:

- a. The mission will occur in the 1995 to 2020 time frame.
- b. Martian surface facilities will be available for assembling and servicing the Marsplane.
- c. All necessary operational facilities, materials and supplies (e.g., fuel) will be available

6. Model/Poster:

Each project group will prepare a model of or poster depicting their Marsplane design, to display during their oral final design report.

* As experienced on Mars.

Appendix D**AAE 241
Aerospace Vehicle Design
Spring 1988****Aircraft Section Schedule**

January 26	First meeting; discuss organization
January 28	Students return project group & technical area preference sheets; sizing lectures begin
February 2	Project groups and technical assignments announced
February 4	Mel DeSart lecture; Using the University's Information Resources
February 9	Sizing lectures end
February 11	Technical area lectures begin
February 16	Sizing exercise turned in
March 1	Paul Czysz lecture; National Aerospace Plane Design
March 15	Written midterm reports due at beginning of class; oral midterm reports
March 17	Oral midterm reports
March 29 & 31	Spring Break
April 21	Design freeze; Col. Stephen Nagel, lecture; Space Transportation System Safety
April 28	Written final design reports due
May 3, 5 & 10	Oral final design reports; aircraft and spacecraft sections combined
May 11	Special evening meeting; dress rehearsal of presentation for the Advanced Design Program Summer Conference

Appendix E

Request for Proposal and Preliminary Design of a Manned Mars Aircraft Space Delivery System

AAE 241
Spring 1988

I. OPPORTUNITY DESCRIPTION

Mars. The question is no longer how, but when.

Soon after arriving on Mars in the year 2005, man will have the desire to expand his exploration horizon. Initially, wheeled vehicles will provide the primary means of transportation on the surface. Unmanned aircraft will be employed for reconnaissance of more distant areas. But nothing can substitute for the presence of man and, as more bases are set up on Mars, a means of transporting men and material to distant sites of interest will be required. A manned Mars aircraft is the next logical step.

Before such an aircraft can begin operations on Mars, it, of course, must be delivered to the Red Planet. Enclosed in a sealed capsule and decelerated into orbit by an advanced aerobrake, the aircraft will await an opportune moment for descent to the surface. Remote sensing instruments will determine if the predesignated landing site is suitable before committing the reentry system containing the aircraft to its final journey to the surface. Afterwards, the orbiting instrument bus will act as a relay satellite supporting the aircraft in its operations.

II. PROJECT OBJECTIVE

The project objective is to develop a conceptual design for the spacecraft system required to deliver the components of a manned aircraft to the Martian surface.

The spacecraft's performance, weight, and cost are very important to acceptance of this type of mission, so approaches should be taken that optimize these parameters in design tradeoffs. The spacecraft should be reliable and easily operated. It should use off-the-shelf hardware where available, but should not use materials or techniques expected to be available after 1998.

III. PROJECT GUIDELINES

A thorough preliminary design study will be conducted to determine major design issues, establish the size of , define subsystems for, and describe the operation of a space delivery system that satisfies the following requirements:

1. The spacecraft will consist of two primary components: the payload reentry system and an instrument bus carrying scientific instruments for remote sensing of the planet's surface. The instrument bus will

Appendix E continued

remain in orbit after separation from the reentry system.

2. The following subsystems are identified for the purposes of system integration:
 - a.) Aerobrake (including orbit capture, reentry, and detachment)
 - b.) Structure (including materials, design, thermal control)
 - c.) Power and Propulsion
 - d.) Attitude and Articulation Control
 - e.) Command and Data Control
 - f.) Science and Radio Relay Instrumentation
 - g.) Mission Management, Planning and Costing
3. The spacecraft's components and payload will be delivered to orbit in the cargo bay of the Space Shuttle and be assembled on-orbit at the space station spacecraft assembly-and-repair facility. The extent of shuttle support should be identified and minimized.
4. The spacecraft will be able to be retrieved by a remote manipulation
5. Nothing in the spacecraft's design should preclude it from performing several possible missions, carrying vastly different payloads to different destinations.
6. The spacecraft will have a design lifetime of four years, but nothing in its design should preclude it from exceeding this lifetime.
7. The vehicle will use the latest advances in artificial intelligence where applicable to enhance mission reliability and reduce mission costs.
8. The design will stress simplicity, reliability, and low cost.
9. For cost estimating and overall planning, it will be assumed that four space delivery systems will be built. Three will be flight ready, while the fourth will be retained for use in an integrated ground test system.
10. Mission science objectives are outlined in the document entitled "AAE 241 Mission Science Objectives."

IV. ORAL MIDTERM PROPOSAL RESPONSE REQUIREMENTS

The technical proposal is the most important factor in the award of a contract. As listed on the AAE 241 Schedule of Events, an oral midterm presentation is required. This presentation will serve as a proposal response outlining the approach to be taken and specific trade studies leading to the final design. While it is realized that all of the technical factors cannot be included in advance, the following should be included in the oral presentation:

Appendix E continued

1. Demonstrate a thorough understanding of the Request for Proposal (RFP) and Preliminary Design requirements.
2. Describe the proposed technical approaches to comply with each of the requirements specified in the RFP. Clarity, and completeness of the technical approach are primary factors in the evaluation of the proposals.
3. Particular emphasis should be directed at identification of critical, technical problem areas. Descriptions, sketches, drawings, method of attack, and discussions of new techniques should be presented.

V. FINAL DESIGN REPORT REQUIREMENTS

The Final Design Report will contain all information obtained or developed for the design of a Manned Mars Aircraft Space Delivery System. It should be specific and complete. While it is realized that all of the technical factors cannot be included in advance, the following should be included in the final design report:

1. Demonstrate a thorough understanding of the Request for Proposal (RFP) and Preliminary Design requirements.
2. Describe the technical approaches used to comply with each of the requirements specified in the RFP. Legibility, clarity, and completeness of the technical approach are primary factors in the evaluation of the final design. Spelling and proper use of the english language are also important.
3. Particular emphasis should be directed at identification of critical, technical problem areas. Descriptions, sketches, drawings, method of attack, and discussions of new techniques should be presented in sufficient detail to permiate engineering evaluation of the proposal. Exceptions to the proposed technical requirements should be identified and justified.
4. Include sensitivity analyses and tradeoff studies performed to arrive at the final decision.
5. Provide an implementation plan for production of the final product.

VI. BASIS FOR EVALUATION

1. Technical Content

This concerns the correctness of theory, validity of reasoning used, apparent understanding and grasp of the subject, etc. Are all major factors considered and a reasonably accurate evaluation of these factors presented?

Appendix E continued

2. Organization and Presentation

The effectiveness of the design report as an instrument of communication is a strong factor in evaluation. Organization of the final design report, clarity, and inclusion of pertinent information are major factors.

3. Originality

If possible, the design report should avoid standard textbook information and show independence of thought or a fresh approach to the project. Does the method and treatment of the problem show imagination?

4. Practical Application and Feasibility

The group should present conclusions or recommendations that are feasible and practical, and not merely lead the evaluators into further difficult or "show-stopping" problems. Is the project realistic from a cost standpoint?

VII. FINAL DESIGN REPORT OUTPUT REQUIREMENTS

Final design project summaries will be submitted to NASA as required by the University of Illinois - NASA Advanced Design program grant. Additionally, the results of AAE 241 projects will be documented in a paper to be submitted to an appropriate forum.

Group final design reports will consist of a clear, concise, and thorough description of the overall design, its major features, and operational capabilities. It will illustrate any special or unique features with clearly labeled diagrams inserted in the text. It will explain and justify options selected to resolve the primary design issues. Students are encouraged to use original and innovative approaches so long as they meet or exceed the design requirements. The following are minimum output requirements:

1. One copy of the final design report will be submitted. It must bear the signatures, names, and student ID numbers of the project leader and design analysts within the group. Designs that are submitted must be the work of the students, but guidance and information may come from outside sources and should be accurately referenced and acknowledged.
2. Final design reports should be no more than 100 double-spaced typewritten pages (including graphs, drawings, photographs, and appendices).
3. Outline of the mission sequence of events, including, but not limited to :
 1. Earth launch date
 2. Mars encounter date

Appendix E continued

3. Surface payload release date
4. A table correlating the primary design issues, related design requirements, options considered, preferred option, and rationale for the option selected. This will not supplant, but summarize, the discussion of trades in the text.
5. Design concepts, including comparison of options considered, major component weights, and total subsystem weights, for the subsystems identified above (where applicable).
6. Overall drawings showing the layout of the spacecraft and its component subsystems. The drawings should be to scale and show major dimensions, the location of major elements of each of the subsystems, and be clearly labeled.
7. Top-level program cost estimates and schedule including major milestones for development, testing, and engineering activities.

VIII. SOURCES OF REFERENCE MATERIALS

Some reference material required to carry out the design will be provided in the form of paper hardcopy, lectures, and electronic media where applicable.

IX. CALENDAR OF EVENTS

Significant activities, homework required, and dates for submission of proposal related materials are presented in the accompanying document entitled "Schedule, AAE 241, Spring 1988."

Appendix F

AAE 241
 Spring 1988
 Spacecraft Section Schedule

This document outlines the AAE 241 schedule referred to in the Request for Proposal for a Manned Mars Aircraft Delivery System section VIII.

Tues 1-26

- introduce project
- handout project RFP
- explain grading
- review course outline
- homework #1: complete class survey, and technical preference/group
- mate questionnaire
 - #2: distill requirements from RFP, noting conflicts and ambiguities

Thurs 1-28

- design theory: what is design, methodology, etc.
- introduce computer utility for design
 - *MIND, Mechanically Intelligent Designer expert system
- homework #3: teach MIND to design spacecraft

Tues 2-2

- more design theory
- systems engineering

Thurs 2-4

- guest lecture: Mel Desart, University of Illinois Library, "Using the University's Information Resources"
- orbital mechanics basics
- communication concerns (line of sight, data rate, etc.)
- trajectory generation for earth-Mars transfer
- introduce computer utility for orbital studies
 - *MULIMP, compute orbit parameters and Δv
- homework #4: transfer orbit Δv analysis

Tues 2-9

- more orbital mechanics
- discuss propulsion subsystem

Thurs 2-11

- recovery day

Appendix F continued

Tues 2-16

- guest lecture: Bob Giubici, MSFC, Marsplane Propulsion Systems
Harold Huie, MSFC, Power Systems for Space Applications
- discuss attitude control subsystem components-function
- discuss thermal subsystem
- discuss power subsystem
- homework #5: thermal trade studies, sizing, component selection
#6: power trade studies, sizing, component selection

Thurs 2-18

- discuss communications subsystem
- homework #8: communications trade studies, sizing component selection

Tues 2-23

- guest lecture: Steve Hoffman, SAIC, aerobrake concerns
- introduce computer minimized shield and propellant mass required
- homework #7: aerobrake shield design

Thurs 2-25

- discuss proposal response oral presentation format
- review and questions
- homework #9: prepare oral response to proposal

Tues 3-1

- guest lecture: John Soldner, SAIC, Mars orbit trajectory options
- discuss structures subsystem
- introduce computer utility for inertia configuration analysis
*INERT, generate composite center of mass, moments of inertia
- homework #10: run INERT to determine acceptable inertia configuration
and draw spacecraft component layout

Thur 3-3

- question and answer time

Tues 3-8

- discuss spacecraft dynamics
- introduction to simulation software
- homework #11: write equations of motion for simple spin instrument bus

Thurs 3-10

- discuss 3-axis dynamics
- homework #12: derive spacecraft 3-axis equations of motion

Appendix F continued

Tues 3-15

- response to proposal oral presentations

Thurs 3-17

- response to proposal oral presentations

Tues 3-22

- guest lecture: Joe Santos, MSFC, Structures for Space Applications
- control options for spacecraft
- introduce computer utility for dynamics and control simulation

Thurs 3-24

- more control system design theory
- homework #13: simple scan actuator gain computation

Tues 3-29

- *spring break*

Thurs 3-31

- *spring break*

Tues 4-5

- question and answer time

Thurs 4-7

- mission planning, command and telemetry requirements
- homework #14: Final report outline

Tues 4-12

- aerobraking revisited

Thurs 4-14

- homework #15: Tiger Team exercise

Tues 4-19

- mission costing

Thurs 4-21

- guest lecture: Col. Stephen Nagel, NASA, STS Safety

Appendix F continued

Tues 4-26

- question and answer time

Thurs 4-28

- misc. topics on work in the "real world"
- spacecraft test considerations

Tues 5-3

- group final design report presentations
- written final design reports due 5:00 pm

Thur 5-5

- group final design report presentations

Tues 5-10

- group final design report presentations

Wed 5-11 (evening)

- special USRA/NASA summary report presentation
- AAE 391 Spacecraft Design Lab presentation/demonstration

Appendix G

AAE 391
Spacecraft Design Laboratory
Spring 1988

Class Roster

Dan Bain
Shawn Holland
John Hoyle
Andy Koepke
Gerhard Lueschen
Sergio Ochoa
John Reily
Matt Zell
Curt Zimmerman

Appendix H

Abstract for paper to be presented at the AIAA Aircraft Design and Operations in Atlanta, September 7-9, 1988.

The Marsplane Revisted
by
K.R. Sivier and M.F. Lembeck

Abstract

The spring 1988 project for the senior-level design course, for the Department of Aeronautical and Astronautical Engineering at the University of Illinois, was a manned flying vehicle for use on Mars. The objective was to incorporate the technological advances of the decade since the Marsplane was studied in the 1970's. The overall specifications were a payload of 1200 N., an unrefueled endurance of 8 hours, and consideration of a rescue mission.

As part of the University's participation in the NASA/USRA University Advanced Design Program, the course was organized with aircraft and spacecraft design sections. The aircraft section was responsible for the Marsplane design and the spacecraft section was responsible for the system to deliver the Marsplane to the Martian surface. The aircraft section was divided into eight separate design groups.

This paper is based on the designs developed by the aircraft design groups.

Appendix I

AAE 241
Aerospace Vehicle Design
University of Illinois
Spring 1988

Student Survey of the Effectiveness of the NASA/USRA Universities Advanced Design Program (N/UADP)

Results Summary

This survey is primarily for the evaluation of the impact of the N/UADP program on the AAE 241 design experience. It is not meant to be, per se, an evaluation of the course or the instructors.

Each of the following questions is multiple choice; circle or check your preferred answer. However, add comments whenever appropriate.

One condition of participating in the N/UADP program is that the project must be "post Space Station". Keep that in mind when answering questions about this semester's design project.

	<u>Aircraft</u> <u>Section</u>		<u>Spacecraft</u> <u>Section</u>	
	No.	%	No.	%
1. Which section of the course were you in?				
aircraft	24	100	0	0
spacecraft	0	0	32	100
2. Your initial interest in the design project was				
high	12	50	16	50
so-so	11	46	15	47
low	0	0	0	0
none	1	4	1	3
3. At the end of the course your interest in the design project had				
increased	11	46	10	31
not changed	6	25	10	31
decreased	6	25	11	34
no interest	1	4	1	3
4. Knowledge that our course was part of a NASA program made the project				
more interesting	17	71	18	56
had no effect	7	29	13	41
less interesting	0	0	0	0
didn't know it was	1	3		

Appendix I continued

5. The value of engineering contacts at NASA's Marshall Space Flight Center was

high	4	17	6	19
so-so	6	25	11	34
low	3	13	2	6
did not benefit from the contracts	11	46	13	41

6. The value of the telecon lectures from NASA was

high	1	4	5	16
so-so	10	42	14	44
low	4	17	13	41
none viewed	7	29	0	0
no response	2	8	0	0

7. The value of the guest lectures was

high	9	38	14	44
so-so	10	42	15	47
low	5	21	3	9

8. Your overall impression of NASA and its programs before the course started was

very positive	8	33	9	28
positive	13	54	15	47
neutral	2	8	6	19
negative	0	0	2	6
very negative	0	0	0	0
no response	1	4	0	0

9. The change in your impression of NASA due to the experiences in the course was

positive	4	17	10	31
none	18	75	18	56
negative	1	4	4	13
no response	1	4	0	0

10. Would you like to work for NASA?

yes	18	75	21	66
don't know	4	17	7	22
no	2	8	4	13

Appendix I continued

11. Because of the course experiences, your interest in working for NASA was

increased	7	29	13	41
did not change	16	67	17	53
decreased	0	0	2	6
no response	1	4	0	0

12. How did participation in this project effect your job interviews this spring?

positively	8	33	6	19
no effect	7	29	13	41
negatively	0	0	0	0
didn't interview	8	33	13	41
no response	1	4	0	0

13. Did participation in this course change your employment objectives?

yes	4	17	9	28
no	20	83	23	72

14. How do you feel about having a team of students from the course representing the University at the N/UADF Conference this summer?

positive	21	88	23	72
don't care	1	4	6	19
negative	2	8	1	3
no response	0	0	2	6

15. Overall, do you feel that your work represents a contribution to the nation's space program?

yes	9	38	8	25
no	11	46	14	44
have no idea	4	17	10	31

Appendix J

1987 ASME Winter Annual Meeting
Boston, MA December 13-18, 1987

Prototype Development of an Expert Spacecraft Design System

by

M.F. Lembeck¹, L.J. Wellnitz², J.V. Santos Jr.³

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ABSTRACT

This paper presents concepts related to preliminary work for the development of an expert system environment for space vehicle design. The example problem is the design of a hypothetical, late 1990's mission that will involve the exploration of a comet by a Multi-bodied Comet Explorer spacecraft. The vehicle is comprised of two major components: a 3-axis controlled instrument bus and a detached, spinning dust shield (Figure 1).

Conceptually introduced by the first author in the waning days of the U.S.-Jet Propulsion Lab Halley Intercept Mission design studies, this configuration decouples the dynamics of dust impacting on the shield from the stringent pointing requirements of the imaging experiments. At the same time, it offers an abundance of simple design, analysis, and simulation tasks that may be carried out by the MIND expert system (introduced in Lembeck and Velinsky, 1987).

The MIND system differs from many other knowledge-based systems in that it can call analysis packages or control system simulation subroutines (as discussed in Lembeck, Dwyer, and Velinsky, 1987) when required by an inference rule. An investigation is being conducted to determine the applicability of the system to spacecraft design. Already, it has been used by students in a NASA-Universities Space Research Association sponsored undergraduate spacecraft design class to carry out requirements definition and component selection leading to a conceptual vehicle design.

¹ Graduate Assistant Section Leader

² Graduate Teaching Assistant

³ Undergraduate Teaching Assistant

Illini Eye Mars

Aerospace engineering students at the University of Illinois are investigating the use of a special lightweight airplane to survey Mars after a permanent outpost is established. The airplane would be pre-delivered to orbit and would be built to fly in the thin Martian atmosphere.

The spring 1986 senior design class worked on a lunar transportation system intended to mine, process and transport liquid oxygen from the Moon to Earth orbit for use as spacecraft fuel. NASA provided phone lectures and background reference material.

Illinois aeronautical and astronautical engineering professor Kenneth Sivier, who runs the design course, heard about the Advanced Design Program in the summer of 1985 and applied. Illinois was accepted and paired with Marshall Space Flight Center in Huntsville, Alabama.

The Mars airplane project is the first opportunity for the aircraft and spacecraft sections of the semester-long design class to work together. The spacecraft group is working on design of the spacecraft to transport the airplane to Mars, including an advanced aerobraking shell and a small telemetry satellite. Finding the proper balance between aerobrake size and propellant quantity is one of the spacecraft group's design concerns. The aircraft group is working on finding the combination of high performance aerodynamics, lightweight structures and fuel efficient propulsion systems to make manned flight on Mars feasible. They then must create flexible mission profiles for the aircraft once it is operational.

The Mars airplane concept was popular in the late 1970s, but engineering difficulties and other practical aerospace realities reduced the interest. Illinois graduate student Michael Lembeck, who teaches the spacecraft group, worked on a version of the Mars airplane as an undergraduate student as part of the annual American Institute of Aeronautics and Astronautics/Allied National Design competition.

"The studies of aerodynamics and composite materials have come along to the point where we can seriously talk about designing such a vehicle," said Lembeck. The July 1987 "Case for Mars III" conference at the University of Colorado included a wide variety of strategies for exploring Mars and convinced Sivier and Lembeck to have this year's design class work on the airplane concept.

Students receive a description of the class project in the form of a request for proposals (RFP). This formal document describes the mission objectives and constraints, yet it is intentionally ambiguous and occasionally even contradictory in order to promote creative design thinking. The students are then split into competing groups and assigned a technical subsystem area (structures, propulsion, aerodynamics, attitude and control, systems engineering) based on course work experience and personal interest.

Design work proceeds through the semester, aided by homework assignments, guest lecturers, instructor feedback and personal initiative. In addition to remote lectures by Marshall engineers, last semester's students heard in-class talks by Jet Propulsion Lab scientists and guests from TRW, Hughes and Science Applications International Corporation of Chicago. The course schedule of design activities is intended to simulate an actual industrial design process, including competition and cost minimization.

Computer work has become an integral part of the class due to a prototype expert system developed by Lembeck that attempts to change engineering design from "an intuitive or creative process to an algorithmic form." The



University of Illinois graduate student Michael Lembeck and Professor Kenneth Sivier examine schematic diagram of a new computer expert system for use in aerospace design class. (Photo: Doug Isbell)

system, known as the Mechanically INtelligent Designer (MIND), can call up various engineering subroutines triggered by rules of inference in order to iterate and finally produce an output.

Students in the class select initial technical parameters based on their knowledge of the project, write rules of interaction, run the MIND program on IBM AT personal computers and then compare the results with project requirements. The expert system approach enables them to examine many design paths, avoiding the manual drudgery that often limits both the extent and types of design solutions considered.

"There is no set way to teach design," said Lembeck. The strength of MIND is that "if you are able to tell the computer how to do it [simulate the steps of design], then you know how to do it."

MIND was used successfully on the spring 1987 space design project, a multi-body cometary explorer spacecraft. Again an idea developed previously by Lembeck (during his work for NASA at the Jet Propulsion Lab on the aborted Comet Halley Intercept Mission), the two-body probe consists of an instrument package protected by a detached, spinning dust shield. The instrument bus floats in the shadow of the shield, isolated from the abrasive, instrument-jarring impacts of the cometary dust. The comet explorer was chosen for study because "just about anything you'll ever see in a spacecraft design shows up in it," Lembeck said.

The potential of MIND is reflected by its use at NASA headquarters, where NASA mission planners use it to juggle such elements as budgets, launch windows, priority payloads and Shuttle availability in order to create Earth-orbiting mission timetables. Lembeck says NASA is pleased with MIND and that the mission planning software is being made available for use by the Mars airplane design groups.

The program has many material benefits. Its funding (about \$20,000 a year at Illinois) has enabled the university to purchase supplies, provide travel money for students to attend the summer conference, pay for a graduate teaching assistant and has led to an entirely new course in building and testing space hardware that will begin this year. A summer internship program has resulted in two of the interns becoming NASA employees at Marshall. —Douglas M. Isbell, Champaign, Illinois

University of Illinois at Urbana-Champaign
U. of Ideas / SCIENCE -- MARCH 88

New design program supports manned space program

Contact: Catherine Foster, Science Editor (217) 244-0469

CHAMPAIGN, Ill. -- The U.S. manned space program has been stalled since the Challenger accident two years ago, and government scientists are working to resume flights later this year. In the meantime, research continues on the next stages of the program.

Aerospace engineering students at the University of Illinois are investigating the complexities of a proposed mission to Mars -- the need for a special lightweight exploratory aircraft, built to fly in the thin Martian atmosphere. While at this stage their work is extremely hypothetical, their research may speed the ideas into reality.

The students are participants in the senior undergraduate design course, which has support from the National Aeronautics and Space Administration and the Universities Space Research Association, a consortium of research universities, through their joint University Advanced Design Program.

U. of I. aeronautical engineering professor Kenneth Sivier, who teaches the design course, explained that NASA's goal is to generate innovative new ideas for space efforts "beyond the space station -- that is, well into the future. Not only do the students produce new ideas, but the projects help improve design education."

The first year the course was offered, for example, the class worked on a lunar transportation system intended to transport liquid oxygen from the moon to the space station for use as spacecraft fuel.

Last year's class designed a two-bodied comet explorer that featured a special dust shield that would allow the vehicle to pass through comet debris successfully.

The Mars project, the subject of this semester's class, will be the first chance for the spacecraft and aircraft design sections of the class to work together. The first will design the spacecraft to transport the airplane to Mars, and the second will design the aircraft itself.

"The studies of aerodynamics and composite materials have come along to the point where we can seriously talk about designing such a vehicle," said Michael Lembeck, U. of I. graduate student who teaches the spacecraft design section.

Design work is performed throughout the semester, simulating an industrial design process involving competition of ideas and cost reduction.

The class begins in the traditional way most government-industry projects begin -- with a formal "request for proposals" issued by the "government," or professor. The hundred-plus class members, divided into project groups of seven or eight, respond as industry would, with an oral response that follows a period of investigation and study. A final report by the competing teams at the end of the semester contains the operational design of the project.